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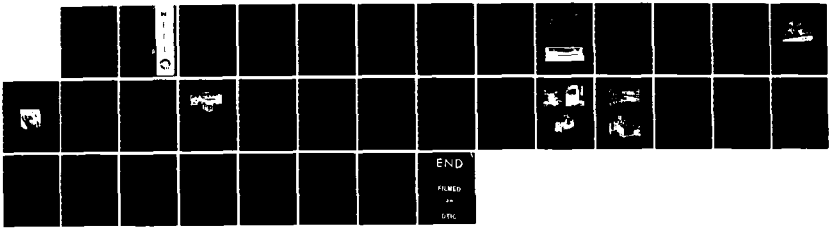

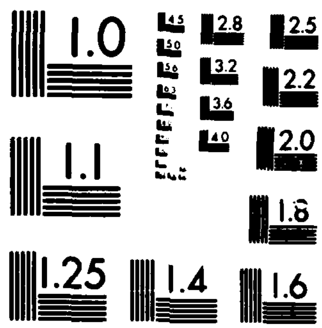

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Blue laser

Xerox Special Information Systems
250 North Halstead Street
Pasadena, California 91107

December 1985

Prepared for
U.S. ARMY CORPS OF ENGINEERS
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This has been a development program to design a low noise, moderate power, blue, hollow cathode laser used for imaging on photoconductors for on-demand color printing. Descriptions of the construction, processing, and testing of experimental unit are presented with recommendations for design improvements.

PREFACE

This document was generated under contract DACW72-84-C-0016 for the U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia 22060-5546, by Xerox Special Information Systems, Pasadena, California 91109. The Contracting Officer's Representative was Mr. James W. Gladden.

ACKNOWLEDGEMENT

The experimental and data contributions to this report by Messrs. S. Casey, C. Strobele, and R. Zimmer are gratefully acknowledged.

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SECTION 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

Contract DACW72-84-C-0016 was begun on 18 September 1984 to develop a blue, hollow cathode laser (HCL) for potential application in the Quick Response Multicolor Printer (QRMP). Figures 1 and 2, show the laser at two stages of fabrication. The technical approach under this contract has been based upon HCL research and development conducted by Xerox over the past ten years. The purpose of this contract has been to design, fabricate, and test a special, blue version of the HCL that could meet the laser performance requirements of the raster output scanner (ROS) in the QRMP.

HCL technology promises some significant technical advantages which should be very important to the QRMP system. Briefly, some of these advantages are:

a. Sufficient power (of the order of 10 mW in blue) at a wavelength of 441.6 nm to efficiently expose a latent image on the QRMP photoreceptor at the desired scan rate. This blue matches the blue response of the type 1, selenium photoreceptor which has been used in the QRMP up to this time.

b. HCLs are modular in construction. Within limits, one can increase the power output by adding modules to an existing design. This program has shown that a seven module blue HCL can produce power levels sufficient for the QRMP ROS exposure requirements.

c. HCLs can operate with very low noise (approximately 1 percent rms) which is important in a laser scanning imaging system. Other types of blue lasers frequently exhibit much higher noise levels (approaching 10 percent) which can be seen as image defects in the output of a laser xerographic printer.

d. HCLs, as currently designed, are constructed primarily of metal and ceramic components which permit them to be more rugged than positive column, glass envelope lasers in mechanically active environments. This improved ruggedness promises to be a highly desired characteristic of this laser when it is included in the field QRMP.

e. The size of a hollow cathode laser is comparable to that of positive column lasers having comparable power levels. A seven module HCL, such as the blue unit constructed under this contract, is about 1 meter in length. Although a shorter length would have advantages and is possibly achievable though additional development, the present dimensions, including length, do not constitute a serious size problem for the QRMP application.

f. Of great importance to the QRMP is the blue wavelength, 441.6 nm, available from the helium-cadmium HCL. This wavelength matches the sensitivity curve of the blue sensitive photoreceptor used in the QRMP and thus minimizes the output power required from the laser. Other blue/green lasers, such as the argon ion gas laser, could be used with this

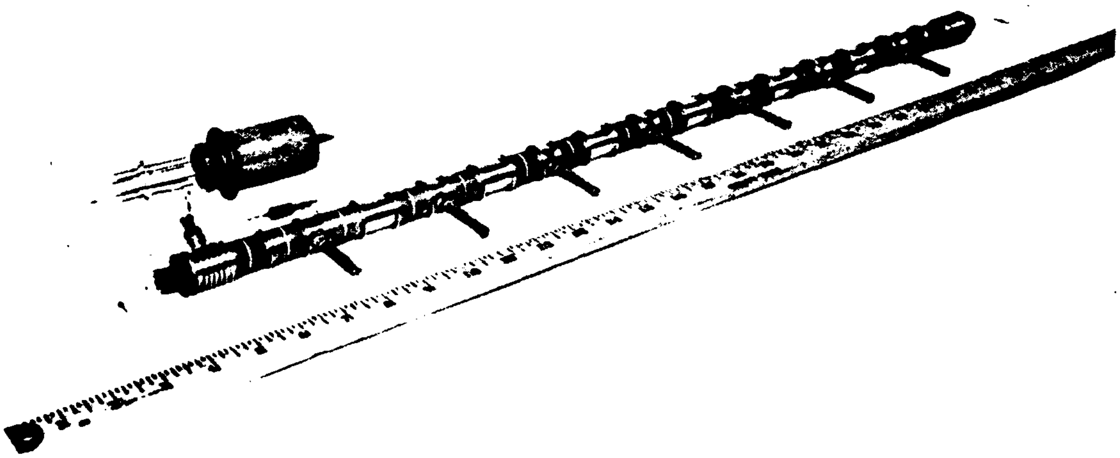


Figure 1. Seven Module HCL without Insulation and Heater Assembly

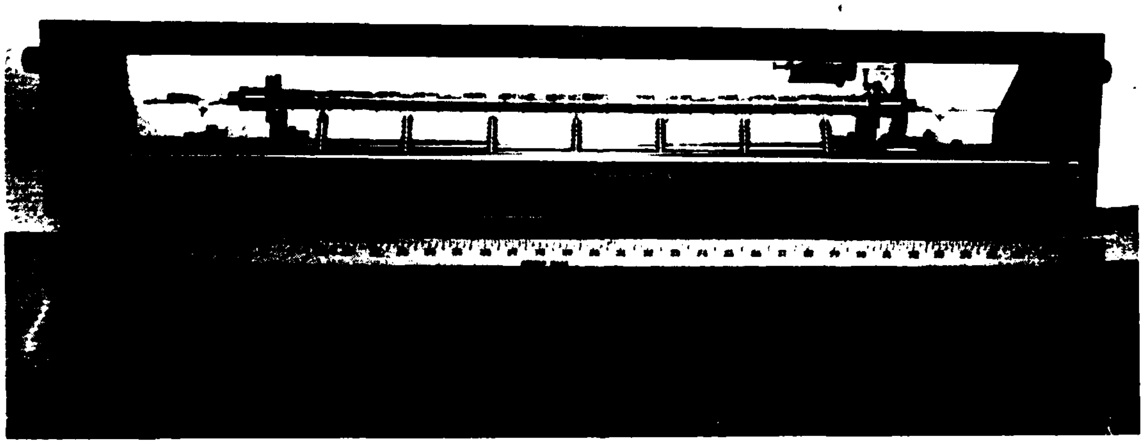


Figure 2. Side View of Seven Module HCL

photoreceptor, but the photo-sensitivity of the selenium at argon, blue-green wavelengths is much reduced compared to the sensitivity of selenium at 441.6 nm.

g. Steady state operation of the HCL includes modest voltages (~300 volts per anode), low discharge power (~48 watts per module), and relatively low temperatures. This is important from power consumption, heat, and physical packaging perspectives. By contrast positive column gas lasers typically operate at several thousand volts and consume significantly more power to produce an equivalent laser output. The efficiency loss in using an alternate laser would in turn require more system power, create additional heat in the QRMP, and in general adversely affect the system environment.

HCL technology is a relatively new technology compared to positive column, gas laser technology which has produced the familiar red, helium-neon and many other gas lasers. Consequently, much of the maturing experience gained over the past 25 years in the development of helium-neon lasers has not yet been acquired for the HCL. This is one of the relative disadvantages of this technology, and was a major reason for performing this development contract. Significant strides have been taken toward designing and developing a blue laser which meets QRMP performance requirements. The promised advantages of a blue HCL over the alternatives of various positive column lasers, makes it well worth further effort and cost to develop and mature this technology. Again, these advantages include (1) adequate power output, (2) very low noise, (3) low voltage and electrical power, and (4) more rugged metal construction.

1.2 SUMMARY

Specific requirements and deliverables of this 12 month contract are as follows:

a. Design, development, fabrication, and test of one hollow cathode blue laser meeting these specifications:
   - 10 mW power, plane polarized at 441.6 nm
   - 1 percent rms noise
   - TEM 01* mode (donut mode)

b. Integration into a color printer for applications testing

c. Data in accordance with CDRL 1423
   - Monthly technical letter progress reports
   - Cost reports
   - Drawings
   - Final report

All aspects of the basic specification for the blue laser have been met. The laser which has been built has operated at or above the power required on numerous occasions, and the low noise level has been achieved on similar occasions simultaneously. The mode can be controlled by adjustments to the mirror system, and TEM 01* can be easily achieved. It can, therefore, be concluded that from the standpoint of basic performance parameters, this blue laser contract has succeded in meeting its goals.

On the other hand, experience gained through testing has shown that the laser in its present state is unstable. This is probably due to a number of causes. One is the inability, now, to control the helium pressure and/or cadmium vapor density within the tube cavity to maintain constant laser performance. Other problems relate to power supply deficiencies, thermal-mechanical instabilities causing laser opto-mechanical misalignments, and perhaps other, yet unidentified, causes.

No work has been planned under this contract to resolve these problems; limited resources have caused us to restrict the program activities to try to identify the causes, define them as clearly as possible, and specify what might be done to correct them in future work. Section 5 addresses conclusions and recommendations for future work.

Because of the instability of the blue laser and problems associated with available color printers such as the QRMP, it was not possible nor desirable to try to integrate the laser into a printer to test its applicability as a ROS laser. Since identifying the causes responsible for laser instability was given the highest priority, all available time after the laser was fabricated was spent in running controlled tests. A few of these tests will be described in subsection 4.2.

Important achievements on the program include:

a. Creation of a laser that, although unstable, can demonstrate desired levels of power and low noise as required for the QRMP ROS.

b. A redesign of the seven unit power supply system resulting in a substantially smaller overall power supply package.

c. The application of the new, Xerox Special Information Systems laser laboratory in Pasadena, California, to this development program.

d. Identification of some of the main causes of laser performance instability.

SECTION 2

TECHNICAL DISCUSSION

2.1 DESCRIPTION OF THE HOLLOW CATHODE LASER

The blue HCL is a member of the general class of low power, gas, continuous wave lasers, which include helium-neon, argon ion, helium-cadmium and others. However, there are many, significant differences which set it apart from these more commonly used gas lasers. Whereas almost all other continuous wave gas lasers are in the positive column class, the hollow cathode laser is distinctive from that class because of its construction and its means of operation. Positive column lasers are so named because the electrical discharge within the laser cavity is colinear with the tube and the laser light beam. It runs from one end of the cavity to the other creating an ionized gas mixture (plasma) which, under proper conditions, has laser properties. The hollow cathode laser has a much shorter discharge path which is radial from the cathode to the anode within the space of each laser module. Figure 3 is a nearly full scale cross sectional view of a single module. Since most HCLs are made up of

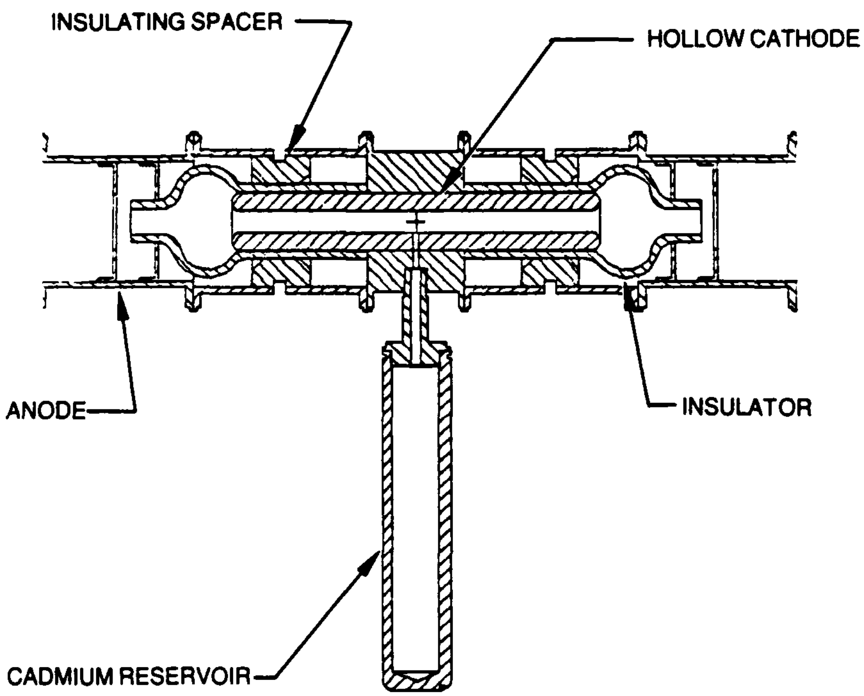


Figure 3. Single Module of HCL (Cross Section)

several modules (the blue one under this contract has seven), there are a number of independent electrical discharge paths active at the same time in the complete laser.

Another distinctive feature of the hollow cathode laser is its metal ceramic construction with a very small amount of glassware. This is considered important in creating a rugged laser for field use when compared to positive column lasers which are mostly glass. Several figures within this report depict the appearance and construction of the HCL. Figure 4 shows the final packaged laser in its mounts,

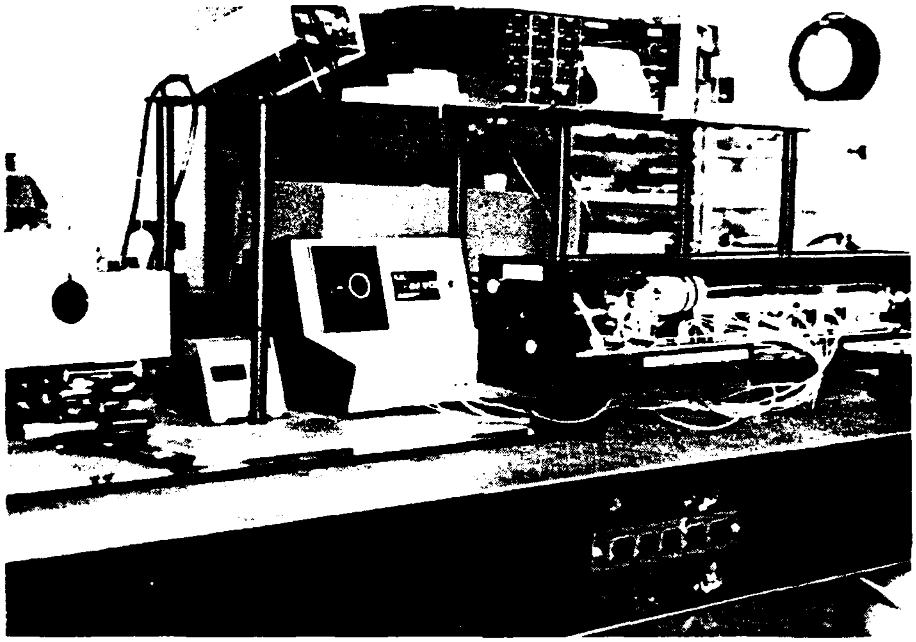


Figure 4. Packaged Laser Operating Under Test

connected to the power supply, and operating under test. Figures 1 and 2 on page 2 show, respectively, the seven module HCL after completion of the welding assembly and after the assembly has been aligned in its support package. Both these latter views show the laser tube before the electrical connections and insulation are added which would obscure the construction details.

Mounted in the end plates of the support package are one flat mirror and one curved (60 cm radius) mirror which together establish the optical geometry and select the wavelength emitted by the laser. The spectral reflectance of the interference coating on these mirrors is one of the important parameters that establish laser wavelength, power, cavity gain, etc.

The end sections on both ends of the laser also contain the brewster windows (slanted windows) which are tilted at Brewster's angle to cause the emitted laser light to be plane polarized. This is an essential feature, because the QRMP ROS optical system demands highly plane-polarized light. Also in this section are located a number of important parts including the auxiliary discharge, shutters, etc. which help to prevent cadmium from depositing on the brewster windows, a phenomenon which would severely shorten laser life.

The main body of the tube is a series of seven modules of metal-ceramic construction; Figure 3 shows a cross sectional view through one module. The seven protrusions hanging below the laser, shown in Figure 1, are the individual cadmium reservoirs for each cathode which contain the cadmium supply for each module. When the tube is cool (not operating), the cadmium is mainly contained in the small metallic cylinder at the bottom of the reservoir. When the tube is operating, the cadmium is heated and is caused to sublime and pass through a very small diameter tube between the reservoir and the main body of the laser. The gaseous cadmium in the cathode area is ionized. The excited ion discharge which flows from anode to cathode tends to force the cadmium back into the reservoir. This ionic current flow causes the cathode structure including the reservoir to be heated. Additionally, resistive heaters surround the cadmium reservoirs and have power intermittently applied to them during operation to control the sublimation rate and thereby control the amount of cadmium in the discharge region.

Figure 5 is a photograph of the main discharge power supply which provides the controlled

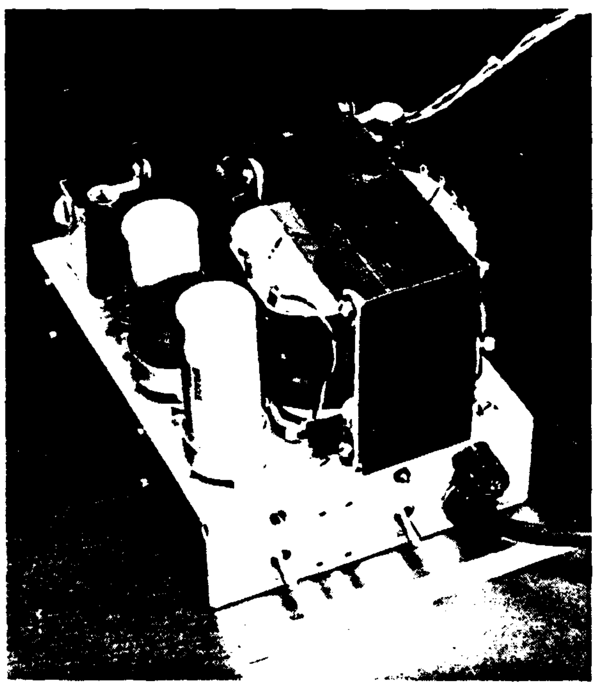


Figure 5. Single Module Main Power Supply

discharge current, the cadmium heater power, and its control circuitry for each module. The blue laser has seven modules and therefore seven such isolated supplies. Figure 6 is the electrical schematic for this supply. Figure 7 displays a pictorial representation of the main power supply connections for a typical module. Figure 8 displays the entire power supply system as it is being used with the blue laser. It contains the seven module supplies plus the two auxiliary circuit supplies. Although this power supply package is still quite large, it represents a significant step in overall size reduction in power supply volume. Obviously additional size reduction would be welcomed.

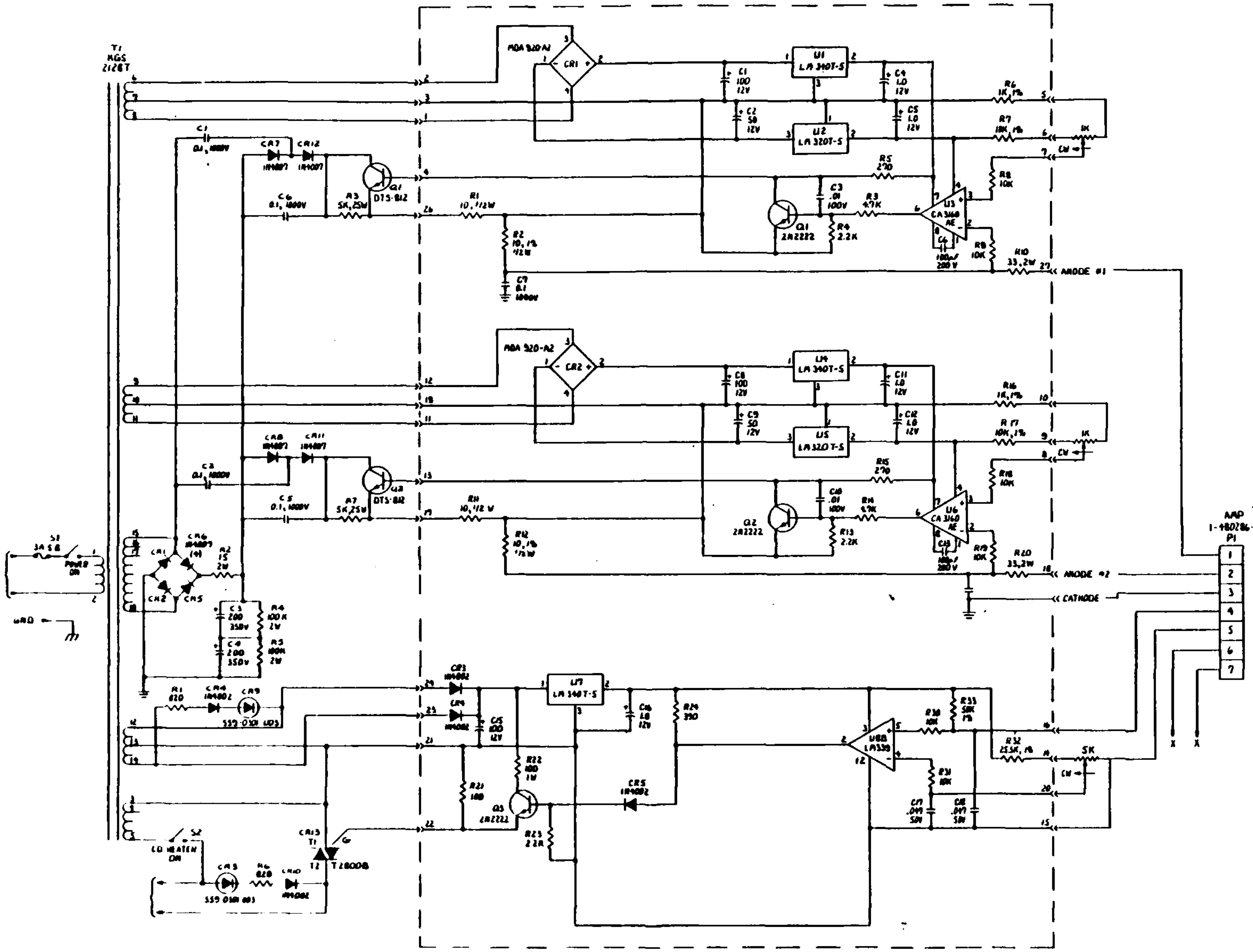


Figure 6. Single Module (Main) Power Supply Schematic

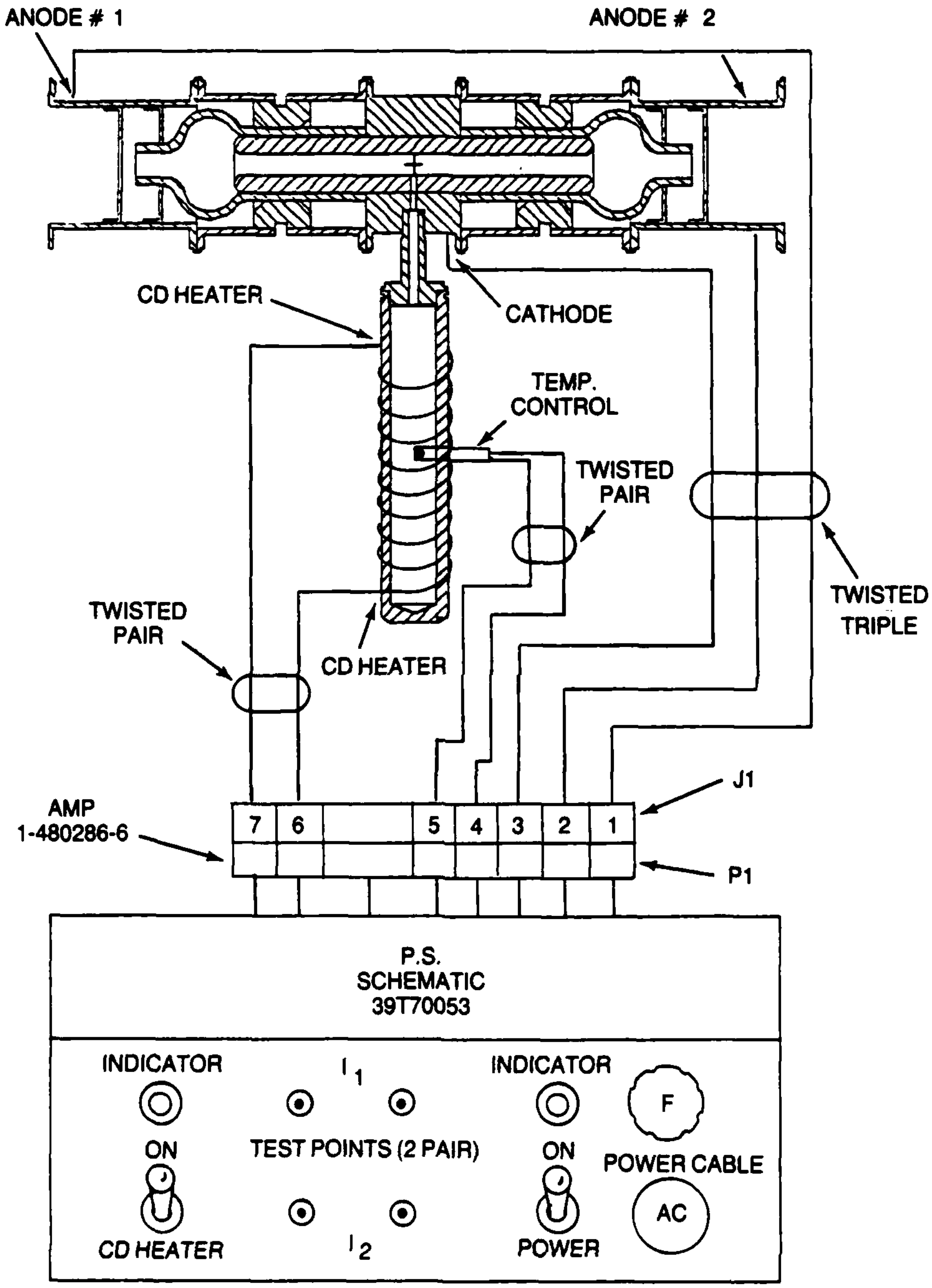


Figure 7. Power Supply and HCL Module Pictorial

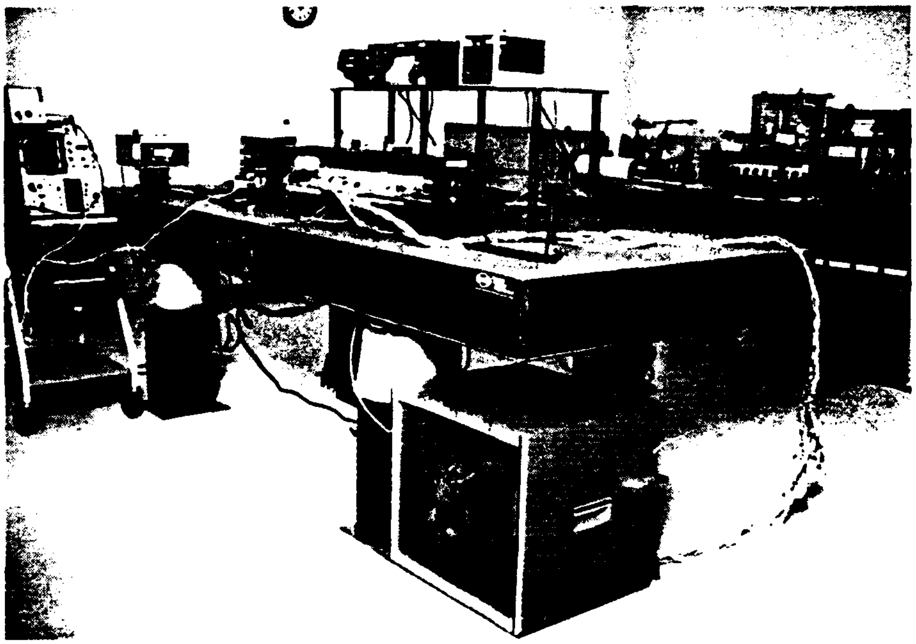


Figure 8. Power Supply System Connected to Laser

When helium becomes depleted in the blue laser through use, it is necessary to replenish it. Figures 1 and 2 show the helium regulator and reservoir (attached to the side of the laser tube) that is used to add helium to the active portion of the laser. This particular regulator has been adapted from another laser design (non HCL) to provide the gas storage and control. Heat is applied to the regulator to cause stored helium to flow through a membrane into the laser tube. In its present configuration, the system operates in an open loop mode. Because of variable operating conditions caused by the helium pressure, some effort has been expended to try to monitor helium pressure changes in the cavity during operation and use the monitored output as an indicator for activating the regulator when the pressure falls. A Pirani gauge was incorporated in the structure of the laser tube to act as a helium pressure monitor. Unfortunately this type of gauge is not as sensitive as desired at the HCL operating pressures of 10 torr. Furthermore, it is very sensitive to external temperature variations. Test data reveals that a cold reading of 110 Pirani units will change to over 130 units when the tube is operating and hot. A better method (more stable with regard to temperature) will be necessary if a satisfactory closed loop pressure control system is to be created

A more comprehensive discussion of the theory and operating characteristics of HCLs may be gleaned from a number of publications. Dr. S. C. Wang, who pioneered this work at Xerox, and his associates have produced these documents which serve as the technical background for this technology. Some important publications include:

New Multicolor Laser for Color Scanning; Proceedings of SPIE - High Speed Read/Write Techniques for Advanced Printing and Data Handling, Vol 390 (1983), pp. 128-133; S. C. Wang, Xerox Electro-Optical Systems.

(Abstract) Negative Glow Discharge White Laser; Journal Optical Society of America, Vol 67 (1977), p. 1424; S. C. Wang.

Panchromatic Hollow Cathode Laser; Proceedings of SPIE, International Optical Computing Conference - Vol 232 (1980); pp. 42-46; S. C. Wang.

(Abstract) Parametric Performance of Hollow Cathode White Laser, IEEE Transactions, Journal of Quantum Electronics, Vol. QE-17 (Dec. 1981), part II, p. 50; S. C. Wang and R. L. Reid.

These references, particularly the first one, SPIE-1983, describe laser operating principles, tube configuration, performance characteristics, and potential applications.

2.2 RELATION OF HCL TECHNOLOGY TO THE QRMP

Experience has shown that the QRMP, in order to achieve the speed, resolution, quality, and efficiency needed for successful operation of the raster output scanner (ROS) requires a blue laser with reasonable power (approximately 10 mW), plane polarization, single mode, and very low noise. It is desirable if the laser also consumes small power and generates as little heat as possible.

At one time (10 years ago) a family of blue, positive column lasers was available to provide the low noise, medium power required for xerography. One such model, which was used very successfully in the QRMP and its predecessor Xerox research printers, was the RCA blue laser, model LD 2186A. RCA discontinued this laser about 5 years ago, and although Xerox procured all the remaining supply of these lasers and tubes to support the QRMP ADP and Xerox research and development activities, the time has come when this type of laser is no longer available to support color printing systems. No other vendor is known to Xerox now that provides a similar laser. The loss of this particular laser technology provided some of the stimulus for this contract.

The technology mix in the QRMP provides an interesting and demanding set of requirements. A blue laser is required because the photoreceptor is blue sensitive (type 1). The alternative to change to a red sensitive photoreceptor to enable the use of a common helium-neon, red laser is not attractive, because the size of the photoreceptor needed is larger than any red sensitive photoreceptor available. It has been estimated that to develop an acceptable red photoreceptor would require a much larger and more expensive program than continuing to mature the blue laser.

Argon ion, gas lasers represent a blue-green alternative to the blue helium-cadmium, but the efficiency of the laser/photoreceptor combination is much inferior to the helium-cadmium laser/selenium type 1 photoreceptor combination. Much higher power would be needed because the efficiency of both the laser and the photoreceptor is lower. Additionally, a deep blue is needed in the raster input scanner (RIS) of the QRMP to achieve the desired color gamut. The argon laser's greenish-blue is not adequate for this colorimetric requirement. It appears that some form of helium-cadmium blue laser operating efficiently and with low noise is needed by the QRMP. The most desirable solution appears to be the hollow cathode laser.

2.3 TECHNICAL MATURITY AND STATUS OF HCL TECHNOLOGY

An objective evaluation of HCL technology seems to follow these lines. Much of the research is over, at least sufficient to define a useful technology. Most of the engineering required to convert a feasible technology into a practical component lies ahead. It has been proven a number of times in Xerox research and now on this program that a HCL can be designed and fabricated to produce predictable results such as power, noise, wavelength, etc. Also fundamental parameters of temperature, pressure, geometric design, power supply design, etc. are beginning to be understood in an engineering sense. But by no means is this technology ready to begin production of standard lasers with known or predictable failure rates or lifetimes. The laser is now ready to enter an important period of engineering in which the operating parameters are evaluated and methods are introduced to control the important ones to achieve a stable and reliable laser having acceptable life.

As the blue laser now stands, it can be made to operate at certain values so long as "tweaking" of controls, alignment, temperature, etc are allowed. In "hands off" operation the laser is unstable and, therefore, unreliable. Sometimes the power will slowly drift downward in level. Under other circumstances it will shift rapidly from one level to another, perhaps even with a mode change. In subsections 4.2 and 4.3 some of the test experiences with this particular laser are discussed in more detail, but the following statement summarizes the overall status of this laser technology: **Feasibility has been established, operation is variable and somewhat unpredictable, failure cause and effect are just beginning to be understood, and substantial engineering remains to be done before the QRMP or any other system can make practical and reliable use of hollow cathode lasers.**

SECTION 3

BLUE HOLLOW CATHODE LASER FABRICATION

This section presents an overview of the steps taken in creating a HCL. There is no intent to provide a detailed step by step account of the process of making such a laser for two reasons: (1) it would make this report unnecessarily long and detailed in a technical area not required by the contract and (2) it would involve a great deal of proprietary (to Xerox) technology.

Figure 9 is an overall laser assembly, process, and test flow chart which shows how subsystems such as the mechanical mounts, power supply, optics, etc., are joined to the laser tube to create the entire laser system. Figure 10 is a simple flow chart showing the progression of the various parts of the laser as they come together to create the final laser tube cavity. Figures 11 through 13 provide views of the new integrated laser facility at Xerox Special Information Systems in Pasadena, California, which is used to assemble and process the laser parts. This new facility represents a marked improvement over the previous hollow cathode laser processing facility and is being used for the first time on this HCL blue laser contract.

The brazing station and its power converter are shown in Figure 11. Here metal and metallized ceramic parts are joined by appropriate high melting temperature alloys under controlled atmosphere conditions to make up subsections of the tube assembly. These subsections of the laser are, in turn, joined by welding as shown in Figure 12. This station is also used to check for leaks in the subassemblies as they are joined together.

After the tube is assembled, the laser tube is mounted in a stable mechanical structure and is processed for proper performance at the station shown in Figure 13. This stable structure provides the mounting points for the external support connections, the mirror support and and their alignment controls, electrical connector mountings, thermal management structures, mechanical and safety protection, as well as providing the stable platform for the laser tube.

During the initial testing, after assembly, additional wiring is integrated into the mechanical housing for the thermocouples used for monitoring the anodes, cathodes, and the cadmium reservoirs of the HCL. Temperature profiles of these segments of the laser provide diagnostic data on the laser while it is operating and being experimentally exercised. Thermocouples are spot welded on to these segments and profile measurements are made on the modules to permit operating condition adjustments.

This completes the assembly and fabrication steps for the HCL. The unit is now ready for processing and testing which will be discussed in Section 4.

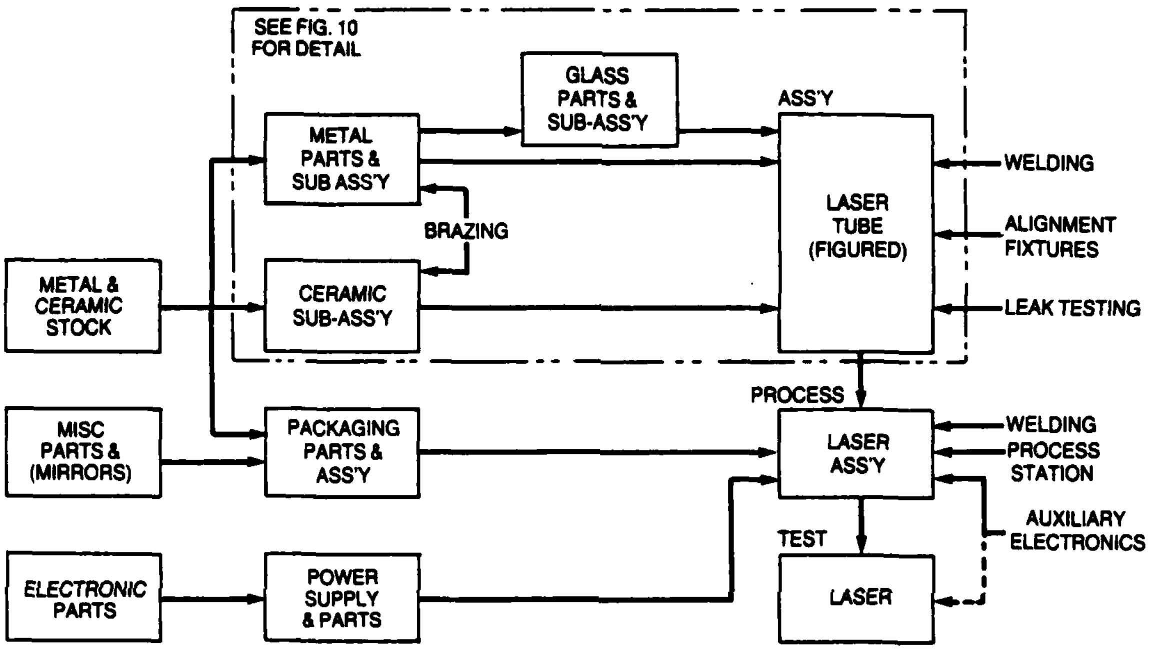


Figure 9. Assembly, Processing, and Testing of Hollow Cathode Laser System

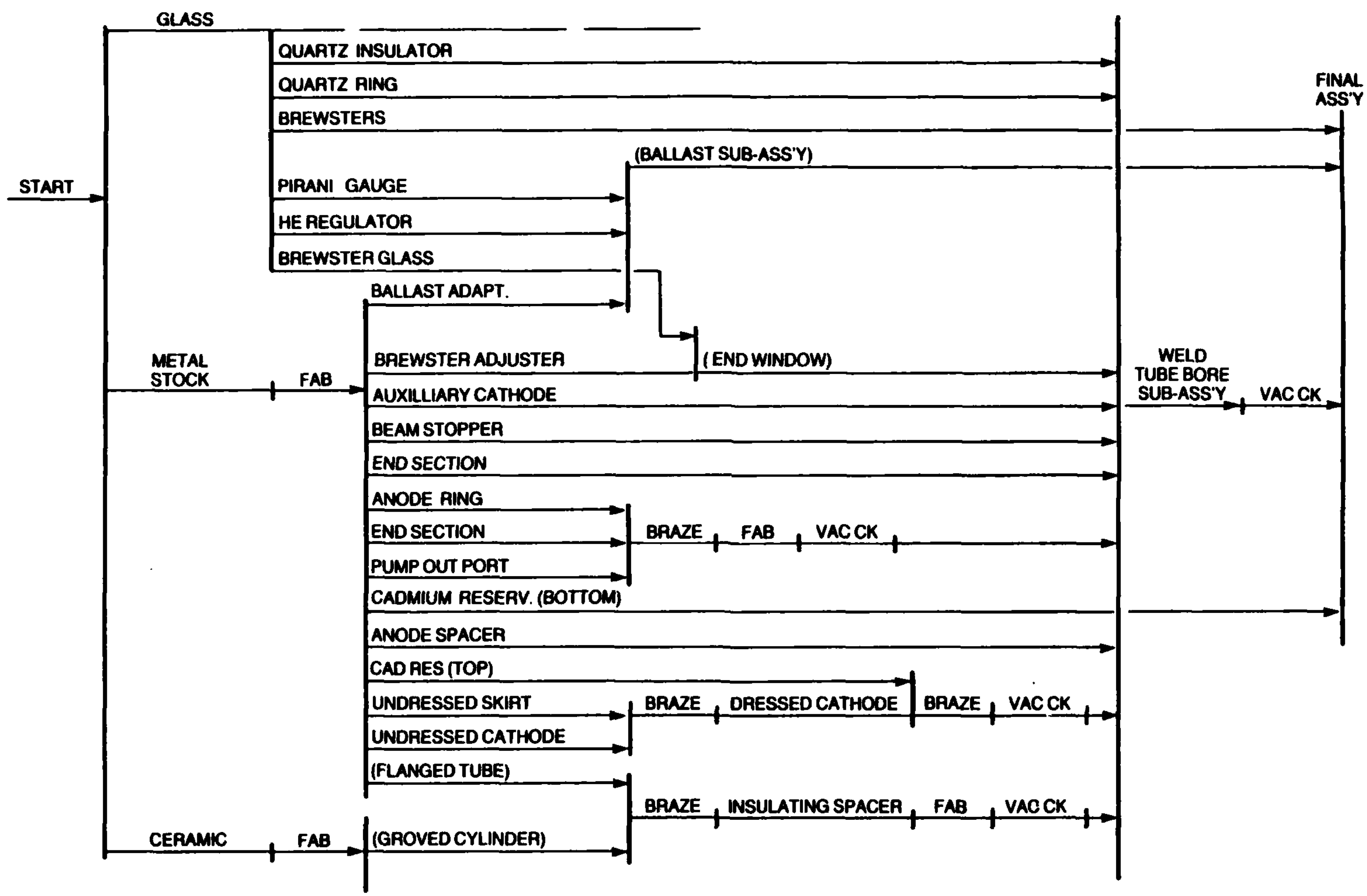


Figure 10. Assembly Sequence for HCL Tube

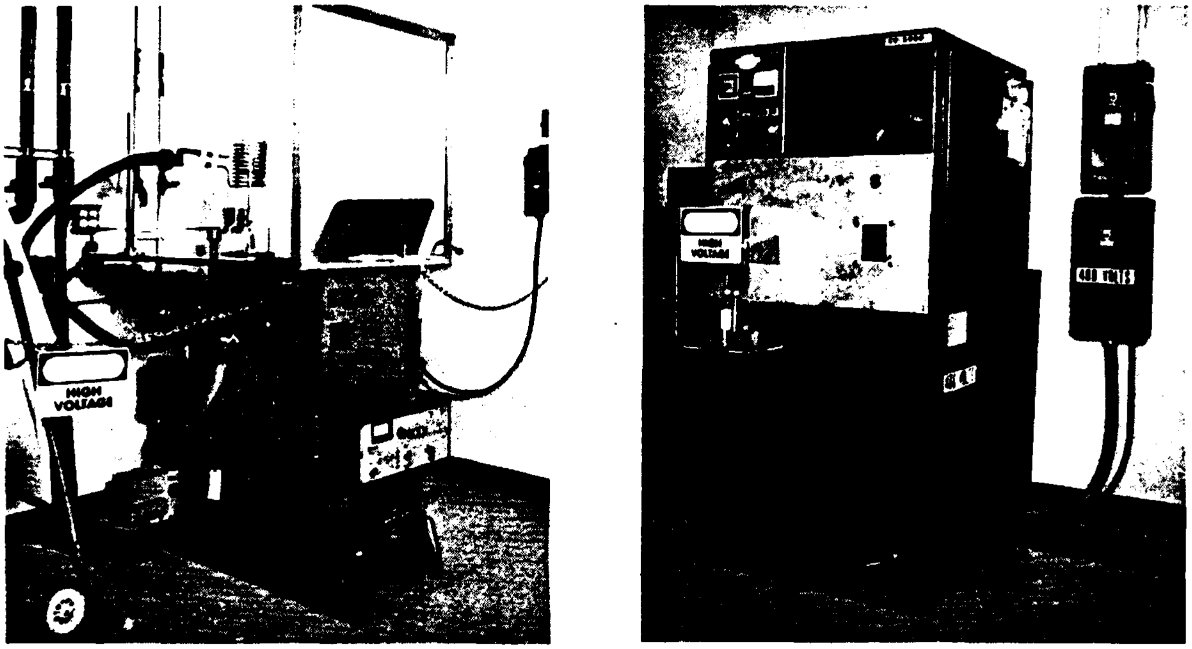


Figure 11. Brazing Station and Converter

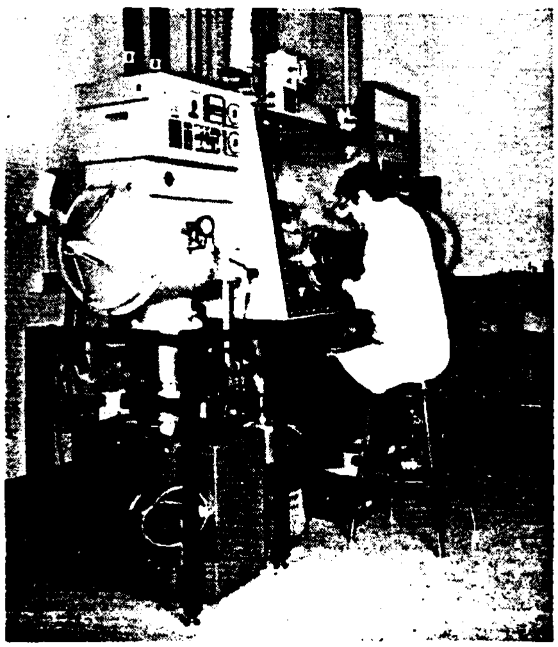
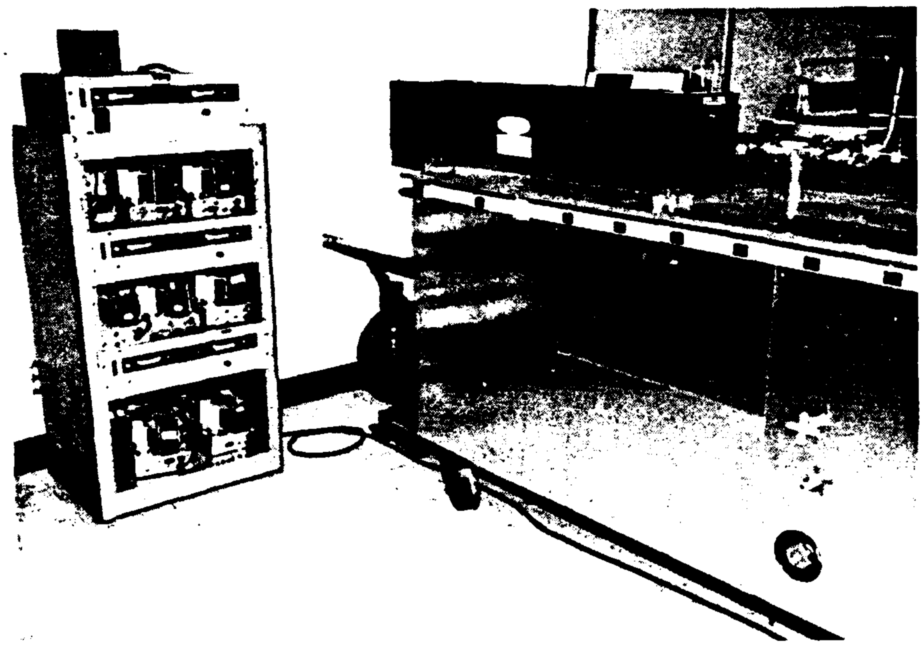


Figure 12. Inert Gas and Low Pressure Welding Station



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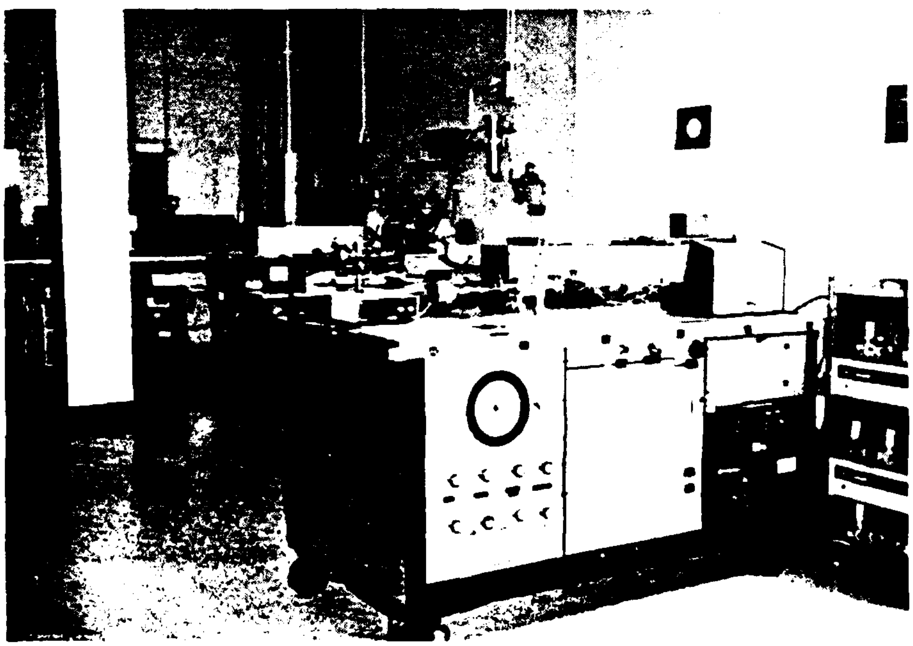


Rear

Figure 13. In-process Testing Station for HCL

SECTION 4

EXPERIENCE WITH THE BLUE LASER

4.1 OPERATIONAL AND PROCESSING EXPERIENCE

After the blue HCL was completed and connected to the new power supply system, a number of tests were begun to ascertain the ability of the laser to meet performance requirements and to maintain stable performance over a continuous run or series of runs. The ability of the laser to meet power, noise, and mode requirements was established early in the test program, but the ability to sustain this performance over a continuous run has not been established. To the contrary, after relatively short runs of only a few hours, the power typically drifts downward to the point where the test has had to be terminated and laser adjustments made to return the laser to acceptable operating levels. At no time, to date, has the laser failed catastrophically; it has always been possible to make some type of adjustment or to process the tube further and return the laser to an acceptable performance level. But it is also true that this design has demonstrated significant instability such that it must be continually "tweaked" to keep it running acceptably. Obviously this must be corrected in future designs if a "practical" laser is to be obtained.

The remainder of this section of this report will be dedicated to relating some typical testing experiences with this laser which have led to the statements above. To relate all of the tests taken over a period of several months would require too much space. Therefore, this discussion should be considered representative of many tests run to try to establish laser failure modes to use in guiding future laser engineering efforts.

Testing and experience with the HCL blue laser can be divided into two parts. Part one deals with laser processing and test results obtained to determine how the processing was progressing and ultimately when it was complete. Part two deals with experimental testing performed on the completed laser after removal from the processing station and is covered in subsection 4.2.

Processing of the laser began on January 9, 1985. Early stages of processing include a number of steps and adjustments to the laser assembly. These steps can actually be considered as the final steps in laser fabrication because some of them involve adding various parts to the partially fabricated laser. During this stage helium is added to the laser while adjusting and checking for proper stable discharge. Heat sinks are added, temporary mirrors used, dust boots added, and mechanical supports installed to help line up the laser bore. All of these actions are taken to produce a properly functioning laser on the processing station. For example, Figure 14 shows how power output has been stabilized by adding a central support to the laser.

The actions required in processing are too varied and detailed to give a full account here, and besides many are proprietary to the Xerox Corporation. In addition to the pumping action of the processing station on the laser tube, numerous adjustments are made in laser operating parameters, temperature, helium pressure, etc., to produce a properly operating system.

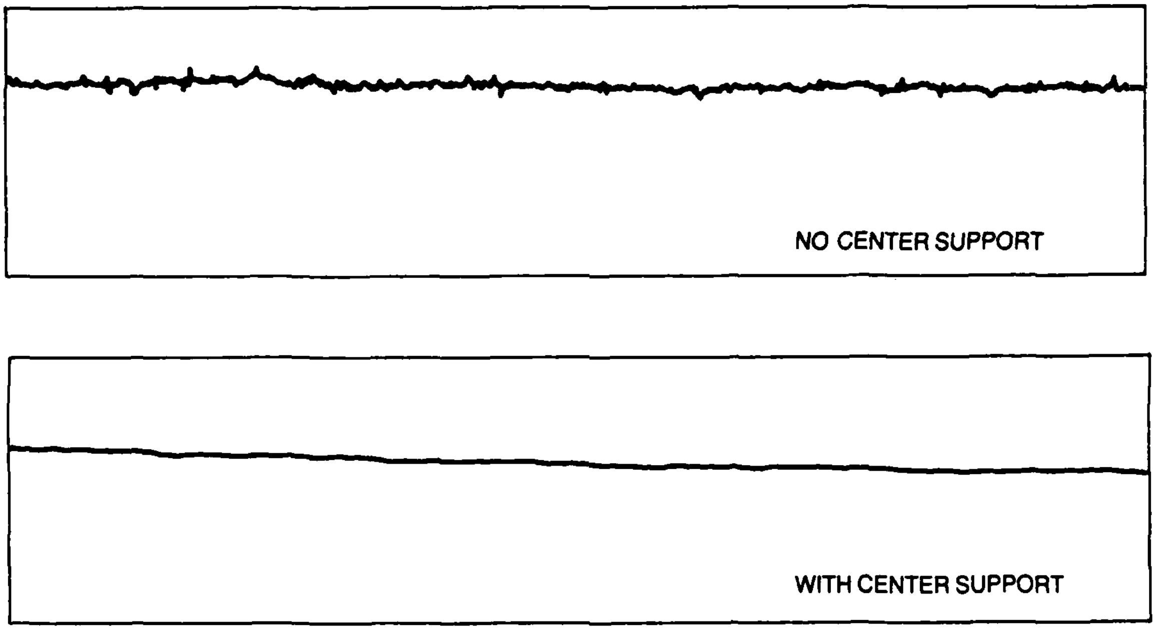


Figure 14. Power Stability with and without Center Support for HCL

Some specific events that occurred during processing included:

a. A power supply failure in one of the seven modules caused a sudden decrease in power output. Cadmium condensed in this section caused by the sudden decrease in temperature and the cessation of electronic pumping which is counted on to pump cadmium back to its reservoir.

b. After this power supply was repaired, insulation was placed near the tube to increase the tube temperature. As the cadmium contamination gradually was sublimated (disappeared), the helium pressure decreased rapidly and power supplies went out of their regulation range. It is believed that helium was being trapped at the coldest regions of the tube where cadmium acted as a "getter" or trapping medium.

c. Recovery was achieved by further insulating the colder module sections to balance the individual anode and cathode temperatures. Power supplies were changed to the new units to reduce ripple. When the system was functioning properly, an acceptable tube power output of 23 mW (multi-mode) was obtained.

The above experience is described not to show how a finished laser operates, because at this stage the laser was still undergoing processing, but instead to show some of the physical phenomena that

occur in the laser cavity which, if not controlled, can cause performance drift or even shut down. Later experience with the finished laser and power supply operating independently of the processing station revealed some similar behavior.

After slightly less than 200 hours of operation on the processing station the tube was "pinched off" to be operated as a self contained unit separate from the processing station.

4.2 PERFORMANCE TESTING

On May 1, 1985, the laser was pinched off and removed from the processing station. At this time it was decided to devise a controlled system of tests (see Figure 15) to establish that the laser could

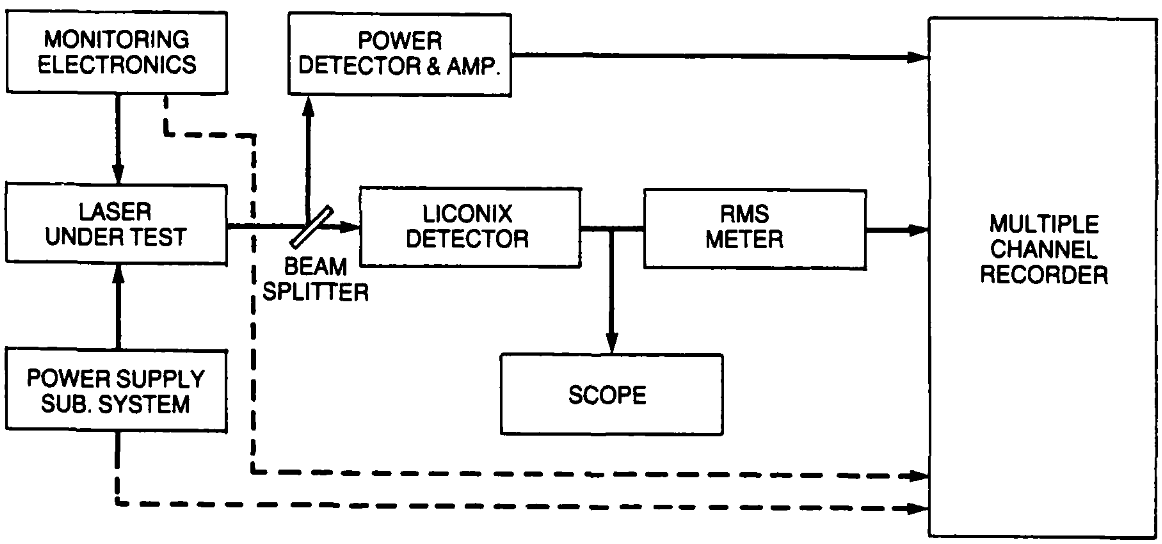
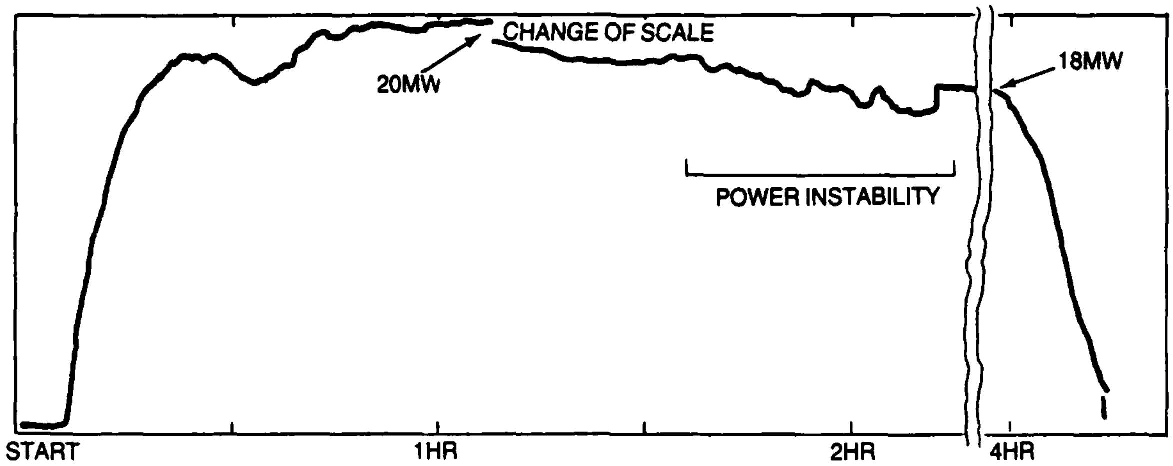


Figure 15. Block Diagram of Laser Test Configuration

meet its performance requirements and also to determine how long the laser would operate acceptably without requiring some kind of mechanical, optical, or thermal adjustment.

A series of tests began on June 7, 1985. A selected sample of these is given below to illustrate some of the kinds of test experiences encountered in this program.

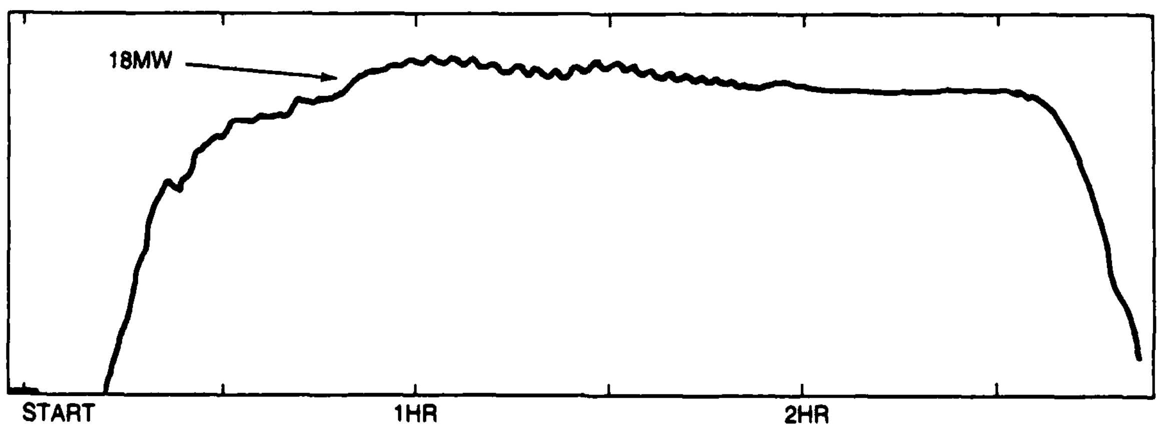


Case 1 – Power Output Graph

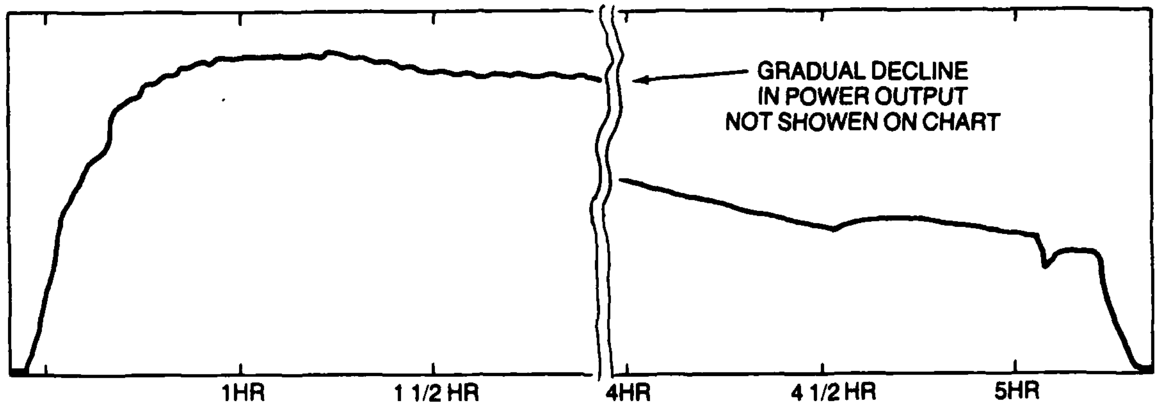
<u>Case 1</u>	Dates of Test -	8-19-85	
	Laser No.85	-	Blue HCL

Test Experience

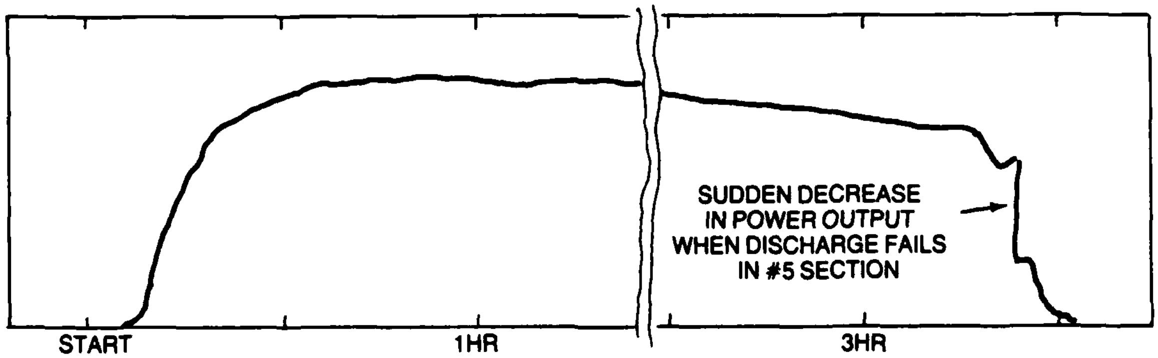
The laser was allowed to warm up and stabilize at 18 to 20 mW blue output, TEM 01* mode with 0.7 percent rms noise. An instability in output power occurred (starting at the 1.5 hour period) that was attributed to mechanical problems with the Invar rod structure.



Case 2a – Power Output Graph



Case 2b – Power Output Graph



Case 2c – Power Output Graph

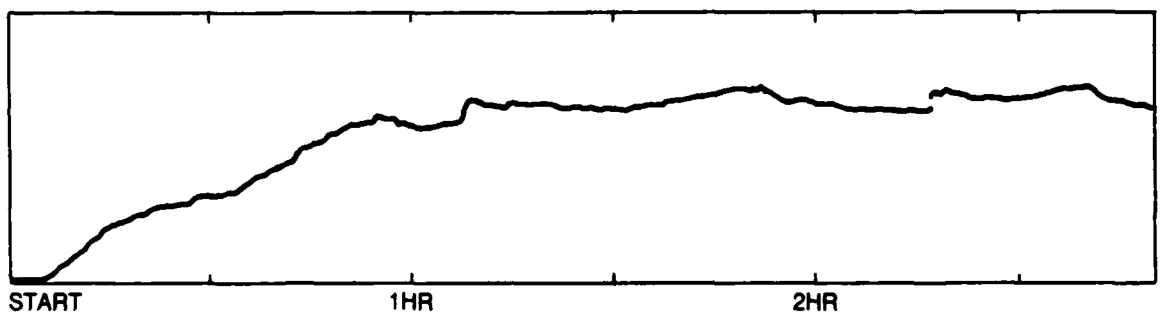
Case 2	Dates of Test -	8-19-85 through 8-21-85
	Laser No.85	- Blue HCL

Test Experience

The laser was allowed to operate without adjustments in its existing mechanical, thermal, optical, and electrical configuration for three consecutive daily runs (labeled a, b, and c). The cadmium reservoirs were operated in the control mode; that is, the laser did not operate when the cadmium was off but did operate when the cadmium heater was active.

The laser was operated without the normal metal screen baffle above the laser tube. Support mounts were holding the laser tight. Power output was noted to oscillate. Over a period of time, as shown in the data plot for the second day, the laser power dropped from 18 to 8 mW. This was attributed partially to decreased laser body temperature and mechanical misalignment.

The laser mount was loosened on one end permitting the laser to be unconstrained during thermal expansion. The power output oscillations stopped but the helium pressure in the laser had dropped and one discharge section No. 5 dropped out (the power supply regulation limit was exceeded when the helium pressure went too low) as shown at the end of data plot for the third day (case 2c). A baffle was placed above the tube and additional insulation was added to selected locations to raise the body temperature and make it uniform. Helium was added to the tube while the unit was not operating to bring the pressure to the normal operation conditions.



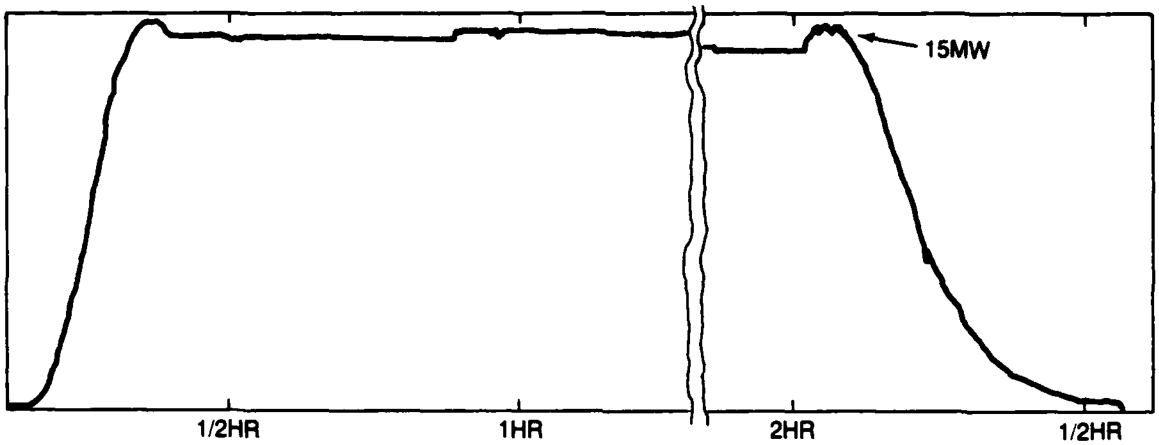
Case 3 – Power Output Graph

Case 3   Dates of Test -   9-3-85

Experience

During warmup and during shutdown the laser again showed instability of power output. The power, on this occasion, was reasonably stable after warmup.

Instabilities could be associated with bending moments introduced by rod structure warping. The mechanical structure was rechecked for freedom of thermal expansion and proper support.



Case 4 – Power Output Graph

<u>Case 4</u> Dates of Test - 9-4-85

Experience

With the metal screen on top of the laser, the helium regulator circuit on, and the rear laser mount unconstrained, fairly stable laser output at 14 mW donut mode was observed. However, the cadmium temperature had not been optimized, resulting in overshoot in laser output during the transition at the start and turn off. The cadmium heater setpoints were adjusted to eliminate the overshoot.

Many other experimental runs have been made on this laser over a period of approximately three months. Some runs were made to optimize cadmium heater temperature, cathode current or helium regulation. When power output increased as the cadmium heaters were turned off at the end of a run, the conclusion was drawn that an excessive amount of cadmium was in the bore of the laser. A series of operating cycles was made in which the cadmium reservoir temperature was decreased resulting in power output stabilizing at a higher level. Noise in the laser also appeared to change in amplitude and frequency during turn on and off.

Sometimes power output would change abruptly in a step fashion. By adjusting one of the laser end mounts to permit unconstrained thermal expansion and contraction of the laser structure, the abrupt output transients were eliminated. After all of these adjustments were made power output was raised to about 18 mW with low noise and proper mode.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Experience gained with the blue laser on this contract has led to a number of conclusions. The most important ones are described below.

Basic Laser Design

The basic laser design which involves the laser cavity design, power supplies, brewster windows, etc. appears to be adequate to meet the requirements established for this program and probably requires little change. This means that the basic plasma tube laser physics has been properly applied to develop a feasible tube design. A seven module laser appears to do the job well, and the cathode-anode design in each module seems to be adequate.

Engineering Design

Whereas the basic physics of the blue laser appears to be well established, the engineering leaves much to be desired. A number of instabilities in performance has revealed deficiencies in the engineering design. Thermal control throughout the laser requires better design. Mechanical mounting should be revised and control systems, to sense and control helium pressure, temperature, etc., need to be found and introduced into the design. Although this contract has sponsored some improvements in the laser power supplies, much more needs to be done to improve electrical control and to reduce the size of the supplies.

To help Xerox ascertain what effective steps may be taken in the future to improve the hollow cathode laser design, an independent outside consultant was brought in to observe the laser in operation and to offer recommendations for improvement. Some of his most important recommendations follow:

a. **Mechanical Mount Changes**

Improve the end mounts holding the laser by eliminating the presently used knife edge contacts. They cause "stiction," which puts sudden changes in the mechanical alignment as well as bending moments into the optical path. Instead one end of the laser would be fixed and would use a flexible joint for the other end. Possible use of a bellows joint (one) to allow for linear expansion has been considered. Gripping the laser in the center with flex joint mounts on either end could also work. These techniques have been tried successfully with other types of gas lasers.

b. **Upgrade the Booting Design**

Using copper or aluminum tubing with copper plating in the booting structure could reduce external contamination of the windows. Viton A O-rings should work very well as a seal for the booting structure.

The use of longer quartz insulators to confine the cadmium in the cathode could replace the need for auxiliary discharge and keep cadmium from plating out on the Brewster windows and other unsuitable places.

c. **Upgrade the Rod Support Structure**

The present Invar rod structure and frame does not adequately isolate external forces from the mirrors and laser tube, allowing misalignments to occur. Use of plates welded to the existing rod structure on each side could substantially isolate the internal mechanical structure and virtually eliminate this cause of misalignment. The mirror mounts would be attached directly to the internal structure to further isolate them from the effects of the stress applied to the external package.

d. **Accelerate Warm Up and Cool Down**

The current laser takes an unacceptably long time for both warm up and shut down. During the testing period a typical period of over an hour was experienced before the laser settled down and operated in a stable steady state manner. It may be possible to step tube current up and down during these transition modes to accelerate warm up and cool down.

e. **Improve the Temperature Control of the Cadmium Reservoirs**

Boring a hole into the reservoir housing to place the thermal control element closer to the cadmium could improve this important control system.

Recommended Future Program

The hollow cathode laser technology requires major attention to a wide assortment of engineering problems many of which have been discussed in this report. A possible plan to follow is outlined below.

a. Continue to test the current blue laser to obtain a better understanding of failure modes and causes.

b. Design and fabricate at least two more complete lasers incorporating engineering changes identified above including, mechanical changes, control system changes, etc.

c. Test these two lasers thoroughly using methods similar to those employed on this program to ascertain if the engineering changes helped to create a stable laser with useful life. This phase may require some iteration and the introduction of additional design changes.

d. Once stable operation of 100 to 200 hours with acceptable power and noise levels has been obtained, fabricate ten more lasers using the identical design for use in extended life testing.

e. Conduct extended life testing (as long as feasible) on the ten lasers.

f. Document the laser design, engineering changes incorporated, and test results in great detail to serve as guidance for the fabrication of laser quantities needed for the QRMP.

Variations on this engineering program plan are possible, and should be considered before undertaking what is probably an 18 to 24 month development program costing several hundred thousand dollars. When the development program is adopted, it must emphasize the required, practical engineering that is necessary to make the laser a reliable unit as well as to further develop the understanding of HCL performance tradeoffs. The program should also sponsor the fabrication of sufficient lasers to ensure the development of significant test data for reliability and life measurements.

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